Geological Society of Malaysia Annual Geological Conference 2000
September 8–9 2000, Pulau Pinang, Malaysia

Coastal Sedimentation and Recent Coastline Changes Along the Seberang Perai Coast, Pulau Pinang

ABDUL HADI ABD. RAHMAN, MOHAMAD ZAKI IBRAHIM & YAJESH V. RAMACHANDRAM

Department of Geology, University of Malaya
50603 Kuala Lumpur, Malaysia

Abstract

The coast of Seberang Perai can be distinctly separated into a northern sandy coast and a southern muddy coast. The mixed sand-mud tidal beach in the north is made up of a clean, fine- to medium-grained sandy supratidal beach, a dirty (muddy) medium- to coarse-grained upper-intertidal sand and a lower-intertidal silty mudflat. The dominant grain size for the sandy supratidal zone display a southward decreasing trend. The grain size ranges between 1.25–2.5 ϕ (~ 0.42–0.18) in the north and between 2.5–3.25 ϕ (0.18–0.105 mm) in the south. This segment of the coast is also characterized by intensive infrastructure development. Large scale man-made structures here are the Dermaga Butterworth, Pengkalan Sultan Abdul Halim and the new North Port. A major coastal embankment and beach filling project is being carried out to slow down coastal erosion, and is nearing completion in Bagan Ajam, Bagan Lebai Tahir, Permatang Kucing and Bagan Belat. Muddy intertidal sedimentation prevails along the southern coast from Pengkalan Sultan Abdul Halim in the north, extending southward to the mouth of Sungai Kerian and the northern coast of Kuala Kurau. This coastal mudflat accretion, which may extend seaward several hundreds of metres and may reach a thickness of more than 1 m thick, is undergoing gradual stabilization and prograding seaward. Maps of the southern coast for the year 1962, 1970, 1977, and 1985 show that the mudflat accretion occurred steadily from 1962 to 1977; however, a very marked change in the rate and pattern of mudflat buildout occurred between 1977 and 1985. The buildout near Batu Kawan by 1985 indicate a significant increase in the rate of mudflat accretion. The mainland coastal mudflat has joined up with the mudflat of Pulau Gedung and Pulau Aman. This may have been related to the construction of the Penang Bridge. The marked contrast in coastal sedimentation between the northern and southern coast may be a function of the geology, the climatic regime and the prevailing marine processes. Sandy beach ridges of the Matang Gelugor Member of the Holocene Gula Formation underlies the northern coastal areas while the southern coast is underlain by the older Undifferentiated Member of the Gula Formation which is composed of clay, silt and sand. Climatically, the northern coast received more precipitation then the south. This may have some influence on the weathering pattern and runoff efficiency in the coastal areas. Sediment transport in the Seberang Perai coast may have been affected by both the south-eastward current and the north-westward current (the flood and the ebb current). The southward-fining trend in sand grainsize observed along the northern coast of Seberang Perai may have been the result of the south-eastward longshore drift. On the other hand, the southern muddy coast clearly show evidences of northward rivermouths displacements and mudflat 'spits' deflections that must have been caused by the prevailing west-northwest longshore currents.

Sedimentasi Pantai dan Pertukaran Garis Pantai Sepanjang Pantai Seberang Perai, Pulau Pinang

Abstrak

Pantai Seberang Perai boleh dibahagikan kepada pantai berpasir dibahagian utara dan pantai berlumpur di bahagian selatan. Pantai pasang surut campuran pasir-lumpur di bahagian utara dibentuk oleh pasir pantai supra pasang surut yang bersih, berbutir halus hingga sederhana, batu pasir atas intertidal yang kotor (berlumpur) berbutir sederhana hingga kasar dan bahagian bawah perantaraan pasang surut terdiri daripada dataran lumpur berlodak. Butiran dominan untuk batu pasir zon supra pasang surut menunjukkan pengurangan ke arah selatan. Saiz butiran menjulat diantara 1.25-2.5ϕ(0.18-0.105mm) di bahagian utara dan menjulat diantara 2.5-3.25ϕ(0.18-0.105mm) dibahagian selatan. Bahagian pantai ini juga dicirikan oleh pembangunan infrastuktur yang intensif. Dermaga Butterworth, Pengkalan Sultan Abdul Halim dan Pengkalan Baru Utara merupakan binaan manusia yang berskala besar dikawasan ini. Aktiviti penambakan pantai dan penimbusan pantai dilakukan untuk mengurangkan hakisan pantai dan dikawasan Bagan Ajam, Bagan Lebai Tahir, Permatang Kucing dan Bagan Belat aktiviti ini sudah hampir siap. Sedimentasi perantaraan pasang surut berlumpur adalah ketara di sepanjang pantai selatan dari Pengkalan Sultan Abdul Halim di bahagian utara dan memanjang kebahagian selatan sehingga ke muara Sungai Kerian dan utara pantai Kuala Kurau. Akresi pantai dataran lumpur yang menganjur beberapa ratus meter dan boleh mencapai ketebalan lebih dari 1m tebal, mengalami penstabilan secara gradual dan menghala ke arah laut. Peta pantai selatan untuk tahun 1962, 1970, 1977 dan 1985 menunjukkan akresi dataran lumpur wujud secara berterusan dari tahun 1962 hingga 1977; namun perubahan yang besar berlaku dari segi jumlah dan bentuk dataran lumpur yang terbentuk pada tahun 1977 dan 1985. Binaan berdekatan Batu Kawan pada tahun 1985 menunjukkan perubahan yang ketara dari segi jumlah akresi dataran lumpur. Dataran lumpur pantai tanah besar telah bergabung dengan dataran lumpur Pulau Gedung dan Pulau Aman. Ini kemungkinan berkaitan dengan pembinaan

Jambatan Pulau Pinang. Perbezaan sedimentasi pantai di bahagian utara dan selatan kemungkinan disebabkan oleh geologi, regim iklim dan proses laut yang efektif. Permatang pantai berpasir di Ahli Matang Gelugor dalam Formasi Gula yang berusia Holosen menindih kawasan pantai utara manakala di bahagian selatan pantai pula ditindih oleh ahli tua Formasi Gula tidak dibezakan yang terdiri daripada tanah liat, lumpur dan pasir. Dari segi iklim bahagian pantai utara menerima lebih penepuan berbanding dengan bahagian selatan. Ini kemungkinan memberikan kesan terhadap corak luluhawa dan kadar larian hujan di kawasan pantai. Pengangkutan sedimen di Pantai Seberang Perai kemungkinan telah dipengaruhi oleh arus Tenggara dan arus Baratlaut (banjir dan arus surut). Corak yang menghalus ke selatan dalam saiz butiran pasir dapat diperhatikan di sepanjang pantai utara Seberang Perai disebabkan oleh pergerakan memanjang pantai ke arah tenggara. Manakala pantai selatan yang berlumpur menunjukkan bukti yang jelas perubahan kearah utara muara sungai dan spits dataran lumpur yang disebabkan oleh arus memanjang dari barat hingga barat laut yang menonjol.

INTRODUCTION

Geography of Seberang Perai

The Seberang Perai area consists of a very flat alluvial plain, which is interrupted by hilly terrain at its eastern margin. The generally undulating to rolling highlands include the two prominent hills of Bukit Mertajam (1787 ft) and Bukit Seraya (1460 ft) (Soo & Selvadurai, 1969). The coastal portion of the Seberang Perai alluvial plain is characterized by numerous marine terraces while the inland areas is distinctly marked by recent and subrecent river terraces (Fig. 1).

The area is drained by two major, natural river systems– the Sungai Muda is located in the northern extreme while Sungai Krian drains the southern parts of Seberang Perai. Medium size rivers are represented by Sungai Prai, Sungai Juru, Sungai Jejawi and Sungai Tengah. These rivers are generally fast flowing in their upper courses but become slow, meandering and characteristically muddy and tidal at the lower courses (Soo & Selvadurai, 1969). The Seberang Perai area is one of the most developed and urbanized coastal zone along the west coast of the Peninsular. Soo & Selvadurai (1969) noted that almost all-original vegetation has disappeared and replaced as the result of human activity. Only patches of Mangrove Swamp Forest and Hill Dipterocarp Forest remain undisturbed.

The coastal areas of Seberang Perai

The coast of Seberang Perai can be distinctly separated into a northern sandy coast and a southern muddy coast. The separation line lies about 1 km north of the present site of the Penang Bridge.

Northern sandy coast

The coastland areas bordering the northern sandy segment of the coast are characterized by a very flat topography mainly occupied by padi fields near the coast and rubber estates in more inland areas. Nearer to the coast, Courtier (1962) mapped and recorded shore parallel, sandy beach ridges that can be traced at least 6 km inland (Fig. 1). This part of Seberang Perai is more densely populated than the southern area; thus, there are more man-made structures in the form of houses, buildings and towns, wharfs and loading bays for ships, and metalled road along the coast. The nearby padi fields are dissected by man-made irrigation canals, which are connected to the natural drainage systems

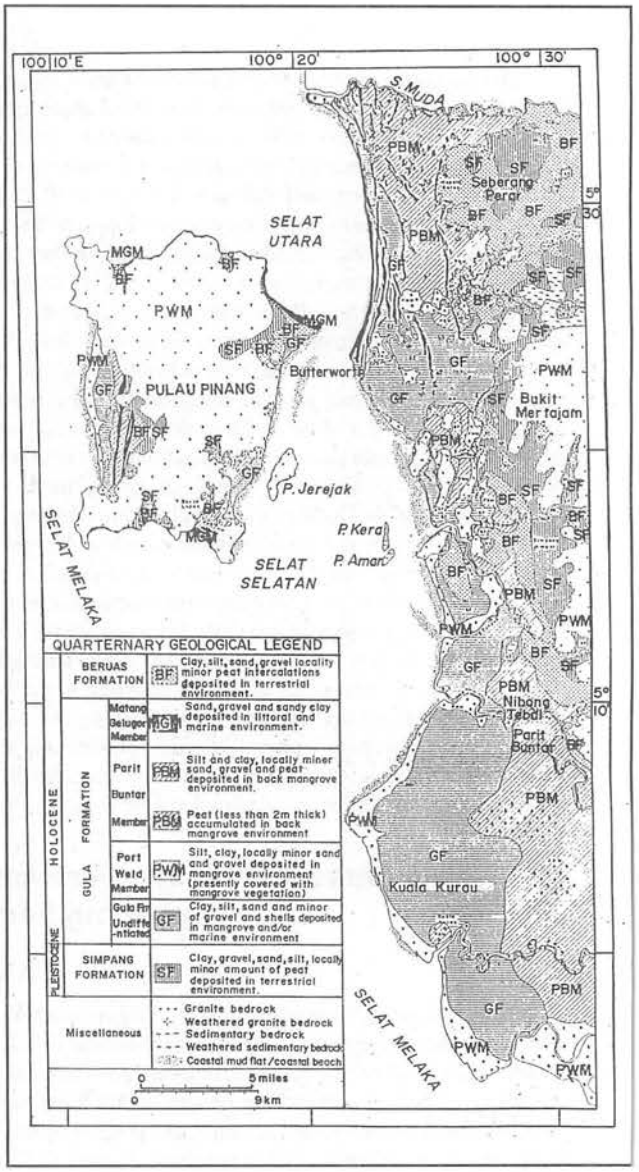

Figure 1: The Quaternary geology map of Seberang Perai and neighbouring areas taken from Kamaludin (1990). This map was drawn based on the 1977 topographic map. Note that the Penang Bridge has not yet been built then.

in one way or another. The river banks of Sungai Muda are generally swampy, while the river banks of Sungai Prai are mostly dominated by nipah trees. It should also be noted that the sandy beaches here are more exposed to the marine processes and forces of the Straits of Malacca.

Southern muddy coast

The coastland areas neighbouring the southern coast is generally flat but dotted with a few isolated, low lying granite hills. This heavily vegetated area is less populated and, hence, less developed and urbanized. Agricultural activity here is dominated by rubber, coconut and oil plantation, with a few small, isolated patches of padi fields. The river banks of Sungai Juru, Sungai Jejawi and Sungai Tengah that drain this part of Seberang Perai are dominated by well developed mangrove forest. The muddy coast is essentially a sheltered coast, due to the presence of the island of Pulau Pinang.

Quaternary Geology of Seberang Perai

A big portion of the Seberang Perai area is underlain by pre-Quaternary granite and sedimentary rocks belonging to the Sungai Petani and the Mahang Formations (Courtier, 1974). The coastal areas in Seberang Perai is also underlain by the Simpang Formation, the Gula Formation and the Beruas Formation, of Quaternary in age. The Pleistocene Simpang Formation, which is made up of gravel, sand, clay and locally silt and peat has been interpreted as a terrestrial, fluvial deposit. The Gula Formation lithologically consists of silt, clay, sand, some gravel and peat and often containing shell fragments. This Holocene unit is thought to have been deposited within an estuarine and shallow marine environment. The Holocene Beruas Formation is a fluvial deposit comprising sand, gravel, clay, silt and occasional peat (Kamaludin, 1990).

COASTAL SEDIMENTATION, SEDIMENTARY ENVIRONMENTS AND MANMADE STRUCTURES

The findings and descriptions presented here are based on studies carried out during the months of March and April 1998. The recent coastline changes described here are based on sequential analysis and interpretation of available aerial photographs and topographic maps.

Northern sandy segment

Records of coastal sedimentation, sedimentary environments and manmade structures along the northern sandy coast of Seberang Perai can be found in Mohamad Zaki (1998). This segment of the coast at present can be informally classified as a mix sand-mud tidal beach. The supratidal part of the beach here is mostly sandy, and in some places are very clean sand (Fig. 2a). A good example is the Permatang Kuching beach and Pantai Bersih beach in Bagan Ajam. However, intertidal deposits are muddy-sand in some places and mud others. Muddy intertidal sedimentation are notable in Kampung Permatang Rawa and Padang Benggali (Fig. 2 d).

The topographic map of 1970 and 1984 shows that this sandy beach is broadest at Kg. Kuala Muda, near the mouth of Sungai Muda (Fig. 4b). This gradually becomes narrower southward towards Butterworth until it is finally terminated near the Pengkalan Sultan Abdul Halim and Dermaga Butterworth wharfs. Results from grain size analysis carried out by Mohamad Zaki (1998) show some interesting trends.

The dominant grain size for the sandy supratidal zone displays a southward decreasing trend. The grain sizes range between 1.25–2.5 ϕ (~ 0.42–0.18 mm–medium to fine)) in the north (Kuala Sungai Muda) and between 2.5–3.25 ϕ (0.18–0.105 mm–fine to very fine) in the south (Bagan Ajam and North Port) (Fig. 3A and B).

The upper intertidal samples are generally coarser, but they also display similar southward fining trend. Samples from Kuala Sungai Muda and Padang Benggali show dominant size range of 0.5–1.25 ϕ (0.71–0.42 mm–coarse to medium) while samples in the southern localities (Bagan Ajam, North Port and Dermaga Butterworth) ranges between 2.5–3.25 ϕ (0.18–0.105 mm–fine to very fine).

The lower intertidal samples are characteristically bimodal, showing dominant modes at around 0.5 ϕ (0.71 mm) and 2.5 ϕ (0.18 mm) (Fig. 3C). The bimodal characters of the plots indicate a higher degree of mixing (very poorly sorted) of sediments within the lower intertidal zone.

Due to severe erosion of the beach caused by the combined effect of marine processes and human activity, a major coastal reclamation and beach filling exercise is being carried out in several stretches of coast between North Port and Padang Benggali (Fig. 2b). Thus, it should be noted that some sand material has been artificially introduced into the area. The authors however believe that the general grain size trend along this coast does reflect the natural, sand transport pattern along the coast.

The southern part of this sandy coast, from Dermaga Butterworth to Padang Benggali, has undergone and is still undergoing intensive development. The most prominent man-made structures here are the Dermaga Butterworth, Pengkalan Sultan Abdul Halim and the new North Port. Further north, in the effort to check coastal erosion, major coastal embankment and beach filling project has been completed in Bagan Ajam, Bagan Lebai Tahir, Permatang Kucing and Bagan Belat. Further north in Padang Benggali, newly built granite-boulder groins are now common features of the coast.

Southern muddy segment

The coastal sedimentation and sedimentary environments along this coastal segment has been documented by Yajesh (1998). The coast here is dominated by muddy intertidal sedimentation. There are only a few small, isolated enclaves of sandy and rocky coast and these are all closely associated with granitic exposures (Fig. 4c). Muddy intertidal sedimentation prevails along this coast from Pengkalan Sultan Abdul Halim in the north, extending

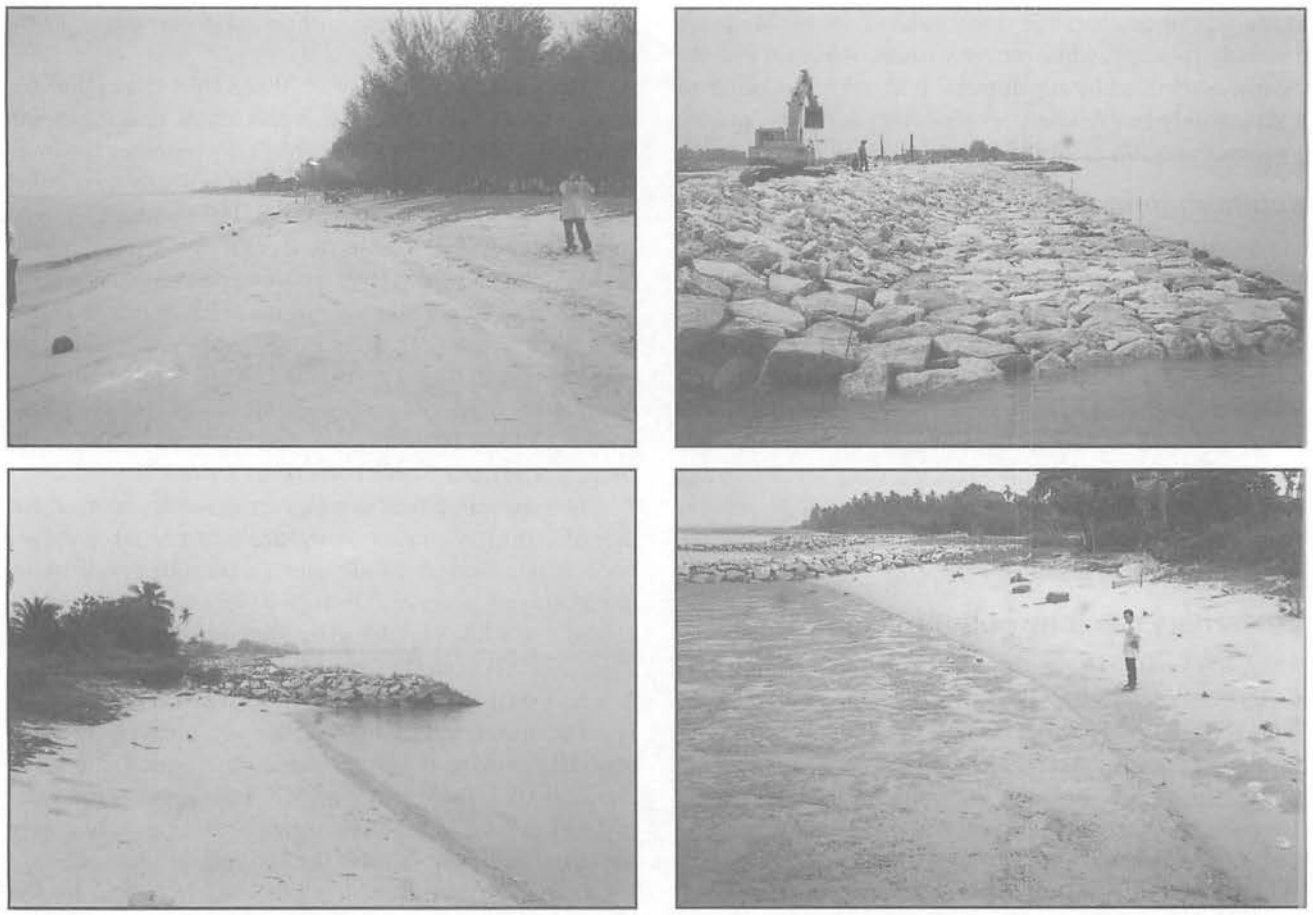

Figure 2: Four views of the northern sandy beach of Seberang Perai. a) A fairly broad, clean and sandy (supratidal) beach near Permatang Kuching; b) Coastal embankment and filling works near Telok Air Tawar; c) A sandy supratidal beach near Padang Benggali during high-tide. Newly constructed granite boulder groins can be seen in the background; d) A different view of the beach at Padang Benggali during low tide. Note the muddy intertidal sediments in the foreground.

southward to the mouth of Sungai Kerian and the northern coast of Kuala Kurau (Fig. 1). This coastal mudflat may extend seaward several hundreds of metres, and generally more than 1 m thick.

Field investigation shows that this mudflat buildout is undergoing a gradual stabilization process and is progressively building out seaward. Pioneer colonies of *Rhizophora* sp., *Sonneritia Griffithi* and *Avecennia* are progressively advancing seaward ontop of the mudflat buildup (Fig. 4 a-b).

Although coastal accretion by mudflat buildup and buildout is distinctly noticeable, there are also evidences of erosion elsewhere. All the river banks close to the coast are affected by erosion. These are shown by cut banks and raised terraces (Fig. 4 d). Where the rate of erosion is more severe, specially designed concrete blocks have been fixed along the river banks to arrest or minimize the effect of erosion.

RECENT COASTLINE CHANGES

The coastline changes described here are based on sequential analysis of topographic maps and air photographs from 1962, 1966, 1970, 1977, 1985 and 1988.

Northern sandy coast

Figures 5a, b and c show the sandy northern coastline of Seberang Perai for the year 1966, 1970 and 1988 respectively. In most parts of the coast no significant changes has taken place. However, at Kg. Kuala Muda, map 5b shows that significant accretion of sands occurred in 1970. This thick buildup of sand was later eroded as shown in map 5c for 1988. It is not clear where the eroded sand were later deposited.

Southern muddy coast

Figures 6a, b, c and d are maps of the southern coast of Seberang Perai for the year 1962, 1970, 1977, and 1985 respectively. In general, these map shows that mudflat is gradually accreted to the coast and slowly advancing seaward. However, a very marked change in the rate and pattern of mudflat buildout occurred between 1977 and 1985. The buildout near Bukit Juru in 1977 has been partly eroded by 1985. On the other hand, at around Batu Kawan, the rate of buildout has increased significantly that by 1985, the coastal mudflat has joined up with the mudflat of Pulau Gedung and Pulau Aman. It is important to highlight something that occurred between 1977 and

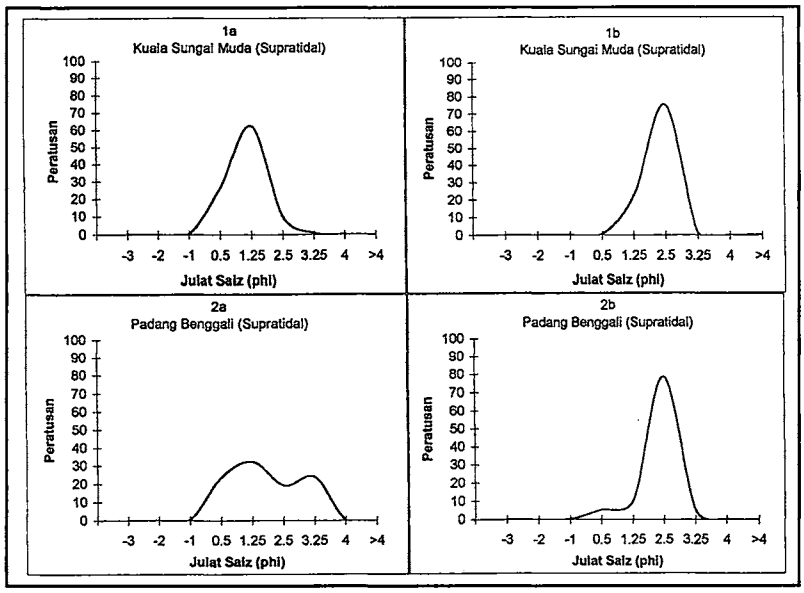

Figure 3A: Grainsize vs Percentage plots (frequency curve) of supratidal sand samples from the northern part of the northern sandy coast of Seberang Perai. Plots 1a and 1b are samples from Kuala Sungai Muda, showing dominant modes at 1.25 and 1.25-2.5 ϕ respectively. Samples 2a from Padang Benggali is bimodal, while 2b show dominant mode between 1.25-2.5 ϕ.

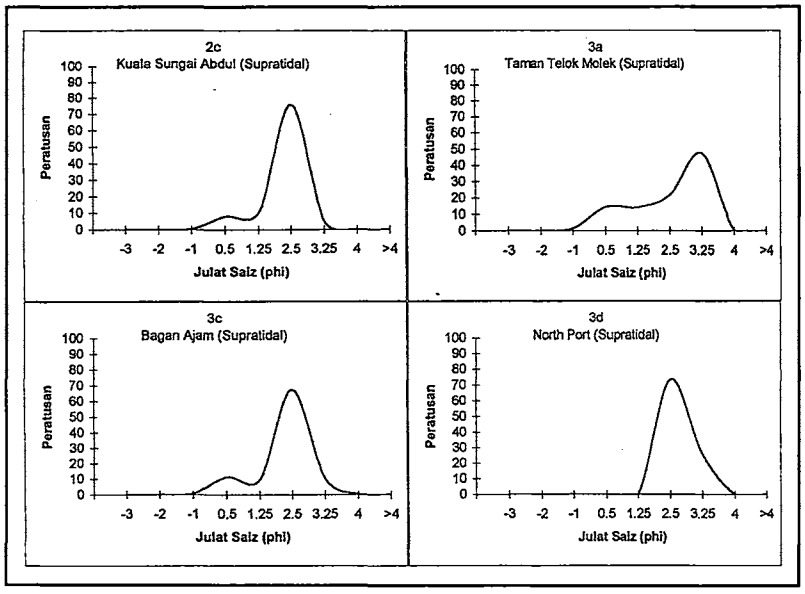

Figure 3B: Grainsize vs Percentage plots (frequency curve) of supratidal sand samples from the southern part of the northern sandy coast of Seberang Perai. Plots 2c and 3a are slightly bimodal, but show dominant modes at 2.5 and 3.25 ϕ respectively. Samples 3c from Bagan Ajam Benggali is also slightly bimodal, but shows a distinct mode at abot 2.5 ϕ while plot 3d from Northport shows dominant mode at slightly above 2.5 ϕ.

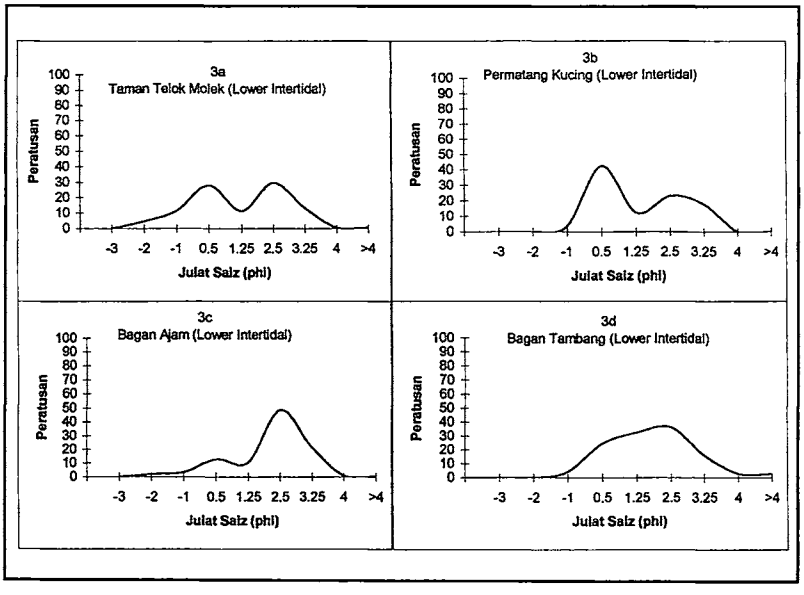

Figure 3C: Plots of grainsize vs sand percentage (frequency curve) of lower intertidal samples from Taman Telok Molek, Permatang Kuching, Bagan Ajam and Bagan Tambang showing distinct bimodal shapes. These plots indicate a higher degree of mixing (lower degree of sorting) within the lower intertidal zone.

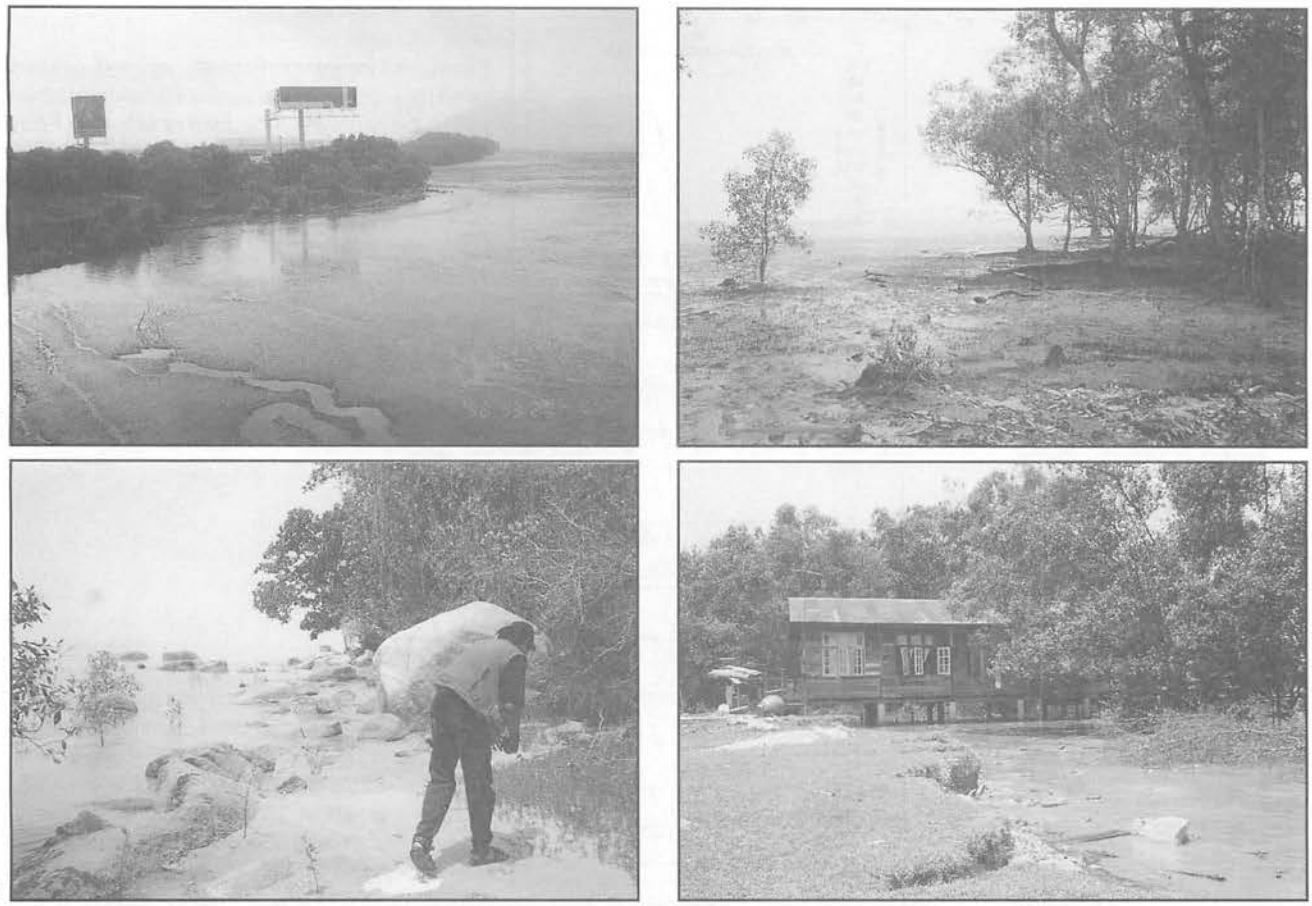

Figure 4: Photographs taken at four locations along the southern muddy coast of Seberang Perai. a) A view from the Penang Bridge showing intertidal mudflat exposed during a lowtide; b) Mudflat stabilization is assisted by the establishment of pioneering species of *Rhizophora* sp. and *Avicennia* sp.; c) A small granite boulder and sandy coast; d) Eroded riverbank of Sungai Juru.

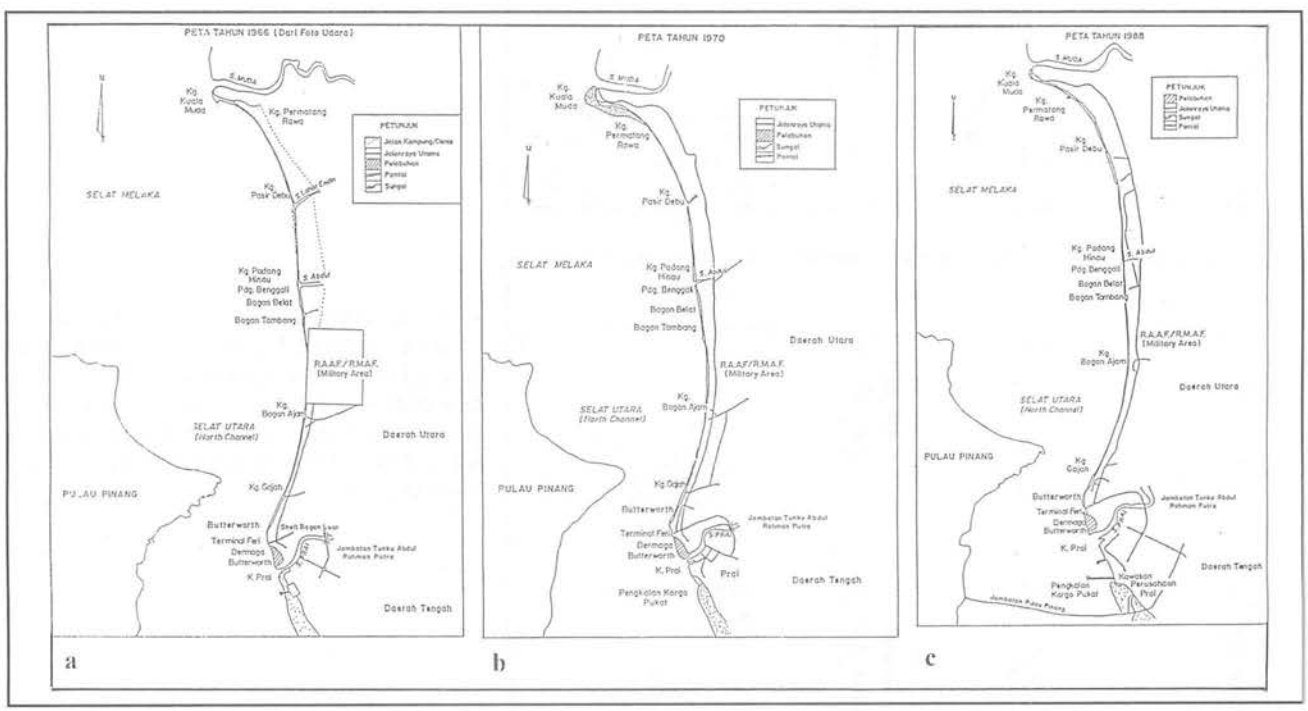

Figure 5: Figures 5a, b and c shows the sandy northern coastline of Seberang Perai for the year 1966, 1970 and 1988 respectively. In most parts of the coast no significant changes have taken place. However, at Kg. Kuala Muda, map 5b shows that significant accretion of sand occurred in 1970. This thick buildup of sand was later eroded as shown in map 5c for 1988. It is not clear where the eroded sand was later deposited.

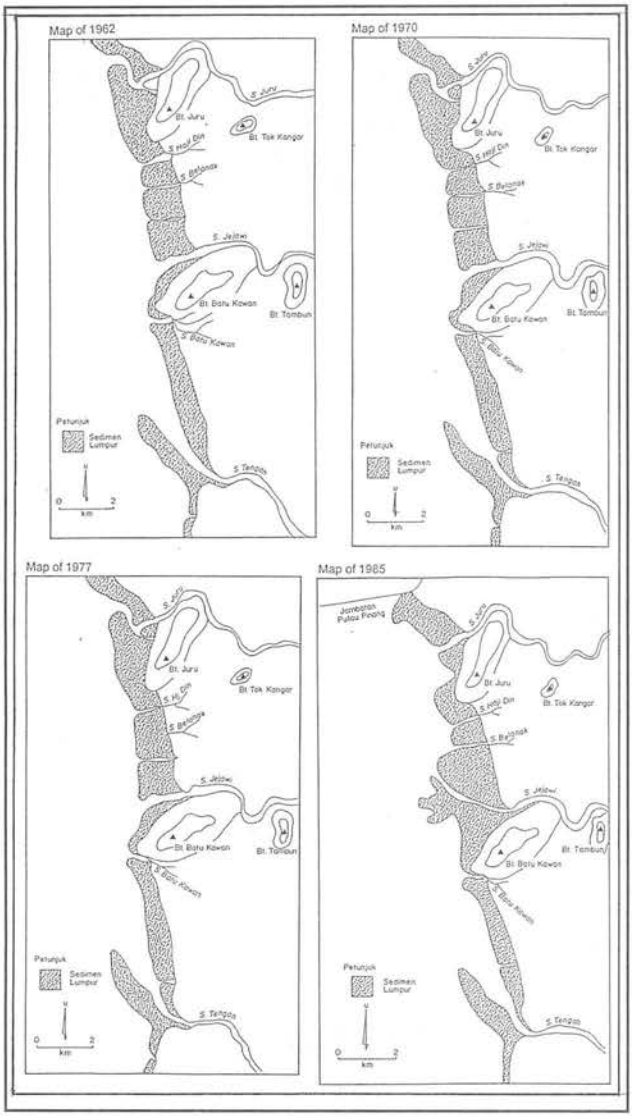

Figure 6: Maps of the southern coast of Seberang Perai for the year 1962, 1970, 1977, and 1985. The most noticeable change occurred from 1977 (Map 6c) to 1985 (Map 6d) where more than 2 km seaward growth of mudflat occurred near Bt. Batu Kawan. Between 1977 to 1985, the Penang Bridge was constructed.

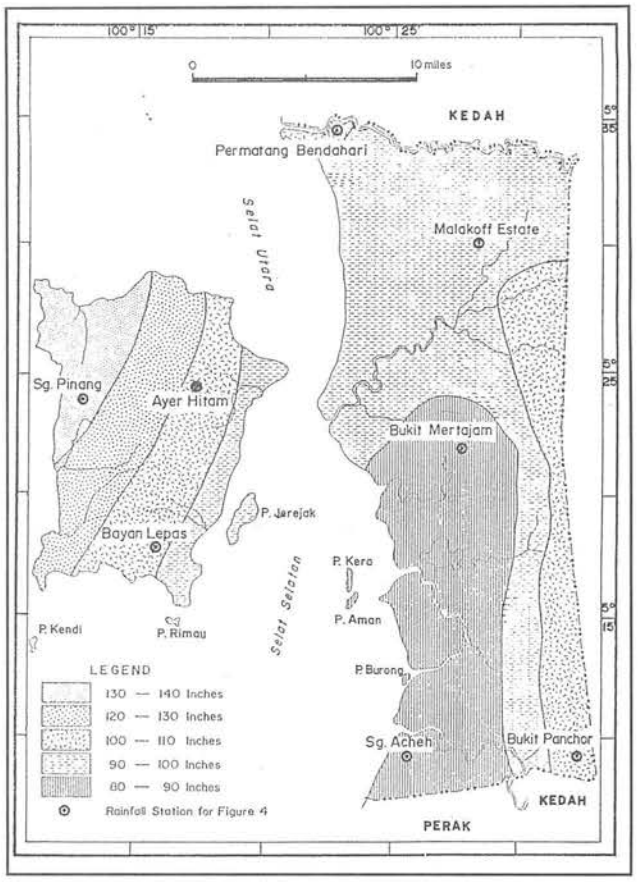

Figure 7: The Mean Annual Rainfall distribution for Seberang Perai and Penang Island for 1950 – 1965 (from Soo & Selvadurau, 1969). Note that the northern areas received more rain than the southern areas.

1985–the longest bridge in Asia, the Penang Bridge, was built!

The north-northwestward growth of the mudflat also reflects the dominant flow direction of the sea currents operating along this coast.

DISCUSSION AND CONCLUSION

This 1998 record of sedimentation and sedimentary environments along the highly developed, densely populated, sandy northern coast of Seberang Perai clearly shows that this coast is rapidly changing from a natural coast to a man-made coast. Erosion is clearly evident, and the intensive beach reclamation and filling program is meant to halt the erosion and protect the man-made structures along the coast. The effects of these massive man-made structures on sedimentation pattern along the coast remain to be seen in the future.

The heavily vegetated, sheltered southern coast of Seberang Perai has experience less human interference. However, some parts of the area is clearly undergoing erosion. Factors contributing to this development are unclear. The southern is distinctly marked by intertidal mud sedimentation. The mudflat buildout shows steady seaward progradation since 1962. The construction of the Penang Bridge between 1977 and 1985 shows strong correlation with the increase in the rate of the mudflat progradation. The construction of the bridge must have changed the sedimentation patterns of these areas.

The marked contrast in coastal sedimentation between the northern and southern coast may be partly explained by the differences in the geology, the climatic regime and the prevailing marine processes. The northern coast is underlain by the beach ridges of the Matang Gelugor Member of the Holocene Gula Formation, which is made up of sand, gravel and sandy clay. The southern coast on the other hand is underlain by the older Undifferentiated Member of

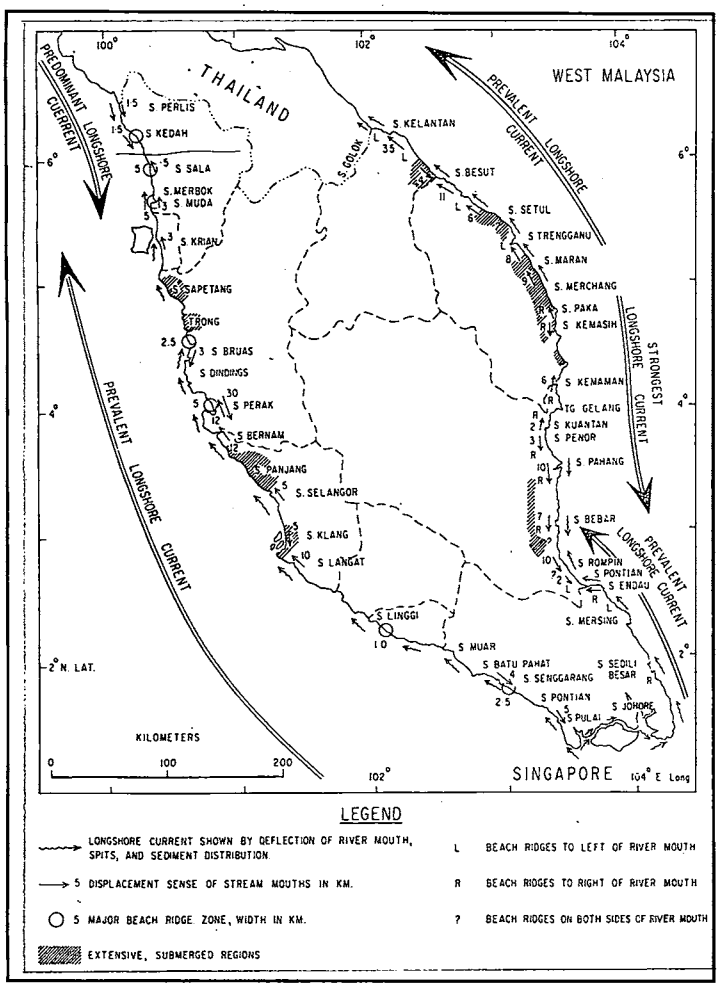

Figure 8: Map of Peninsular Malaysia showing the major, prevalent longshore currents (tidal currents?) in the Straits of Malacca after Tjia (1972). Sediment transport in the Seberang Perai coast may have been affected by both the south-eastward trending current and the north-westward current shown here.

the Gula Formation, which is composed of clay, silt and sand (Fig. 1). These two factors must have been the source of some of the sand in the north, and some of the mud in the south. The two regions also experienced different climatic regime. Figure 7 shows the Mean Annual Rainfall distribution for Seberang Perai and Penang Island for 1950–1965 (from Soo & Selvadurau, 1969). While the northern coast received between 90 to 100 inches of rainfall, the southern coast only recorded between 80 to 90 inches. This factor must have some influence on the weathering pattern and runoff efficiency in the coastal areas, and the hydrodynamic forces in the sea. The map shown in Figure 8 is taken from Tjia (1972), showing the major, prevalent longshore currents in the Straits of Malacca. Sediment transport in Seberang Perai coast may have been affected by both the south-eastward trending current and the north-westward current. The southward-fining trend in sand grainsize observed along the northern coast of Seberang Perai may have been the result of the south-eastward longshore drift. On the other hand, the southern muddy coast clearly show evidences of rivermouths displacements and mudflat 'spits' northward deflections that must have been caused by the prevailing west-northwest longshore currents.

REFERENCES

Courtier, D.B., 1962. Note on terraces and other alluvial features in parts of Province Wellesley, south Kedah and north Perak. *Prof. Pap. Geol. Survey Dept. Fed. Malaya*, E62.1-T, 6 p.

Courtier, D.B., 1974. Geology and mineral resources of the neighbourhood of Kulim, Kedah. *Geol. Surv. Malaysia, Map. Bull.* 3, 50p.

Gobbett, D.J. & Hutchison, C.S. (eds.), 1973. *Geology of the Malay Peninsula*. Wiley, New York, 438p.

Kamaludin Bin Hassan, 1990. A summary of the Quaternary geology investigations in Seberang Perai, Pulau Pinang and Kuala Kurau. *Geol. Soc. Malaysia Bull.* 26:47-53.

Mohamad Zaki b. Ibrahim, 1998. Kajian Sedimentologi Enapan Resen sepanjang pantai Seberang Perai dari Jambatan Pulau Pinang sebelah Utara. Laporan Projek S.M. Sains Univ. Malaya (unpublished), p. 31.

Soo, S. W. and Selvadurai, K., 1969. Reconnaissance soil survey of Penang and Province Wellesley. *Malayan Soil Survey Report* No. 1/1969, 66p.

Tjia, H.D., 1973. Geomorphology. *In:* Gobbett, D.J. and Hutchison, C.S. (eds.), *Geology of the Malay Peninsula*. Wiley-Interscience, New York, p. 13-24.

Yajesh V. Ramachendram, 1998. Kajian Enapan Resen dan Batuan Granit ke Selatan Jambatan Pulau Pinang, Seberang Perai. Laporan Projek S.M. Sains Univ. Malaya (unpublished), p. 29.